# Subantarctic drying and dramatic glacier wastage in Kerguelen archipelago

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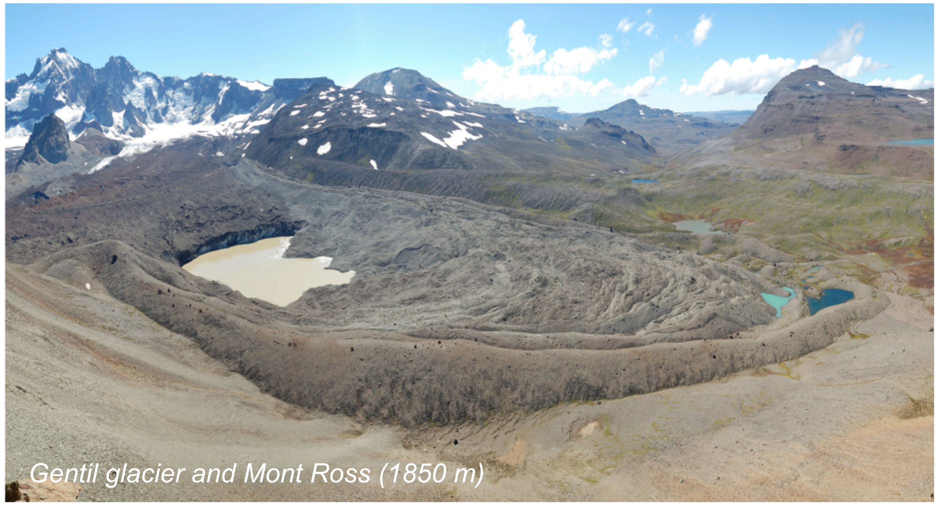


Ateliers de Modélisation de l'Atmosphère – AMA, January, 2015

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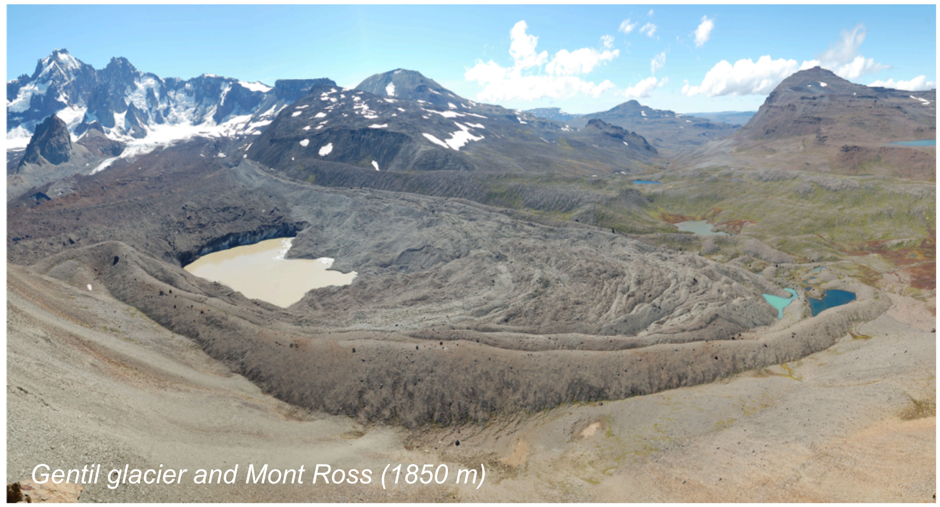

*Gentil glacier and Mont Ross (1850 m)*

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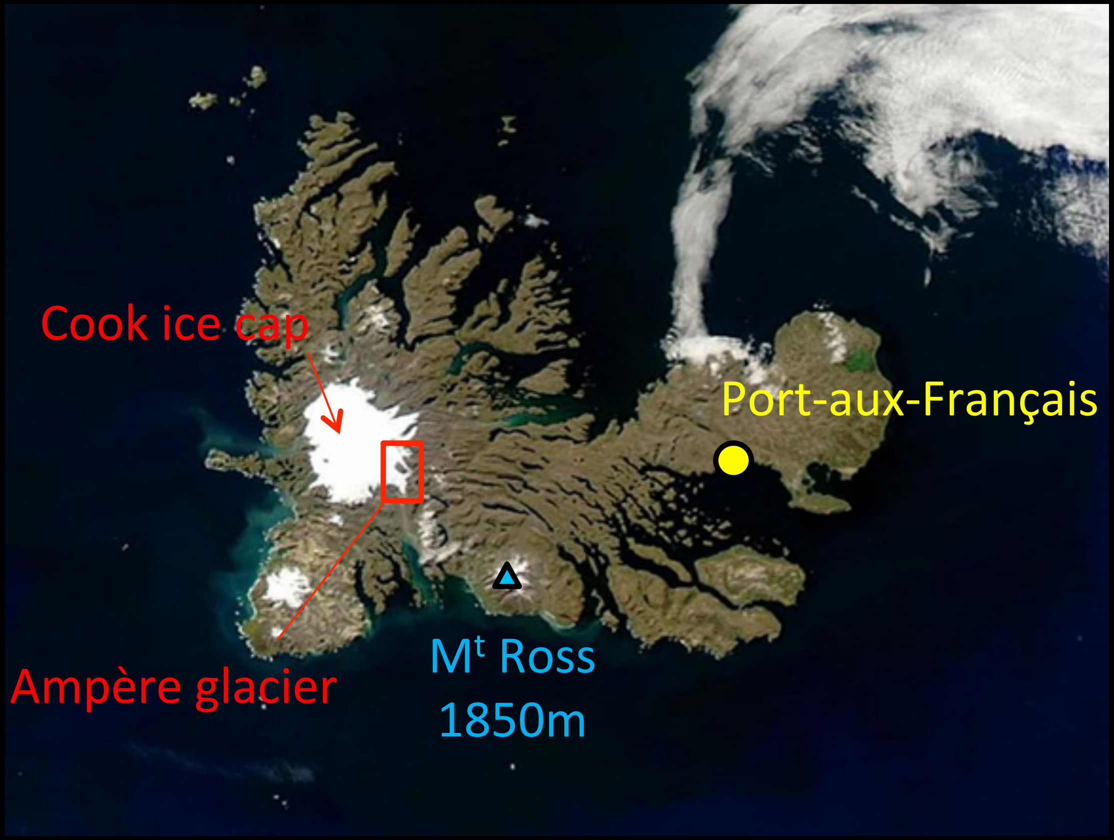
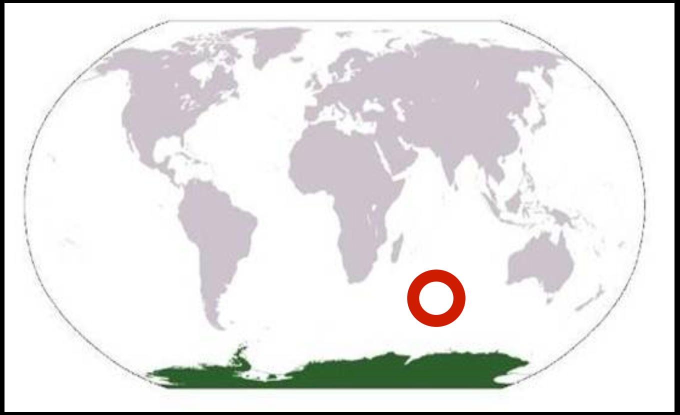
## Location




Kerguelen(49°S, 69°E)
Southern Indian ocean

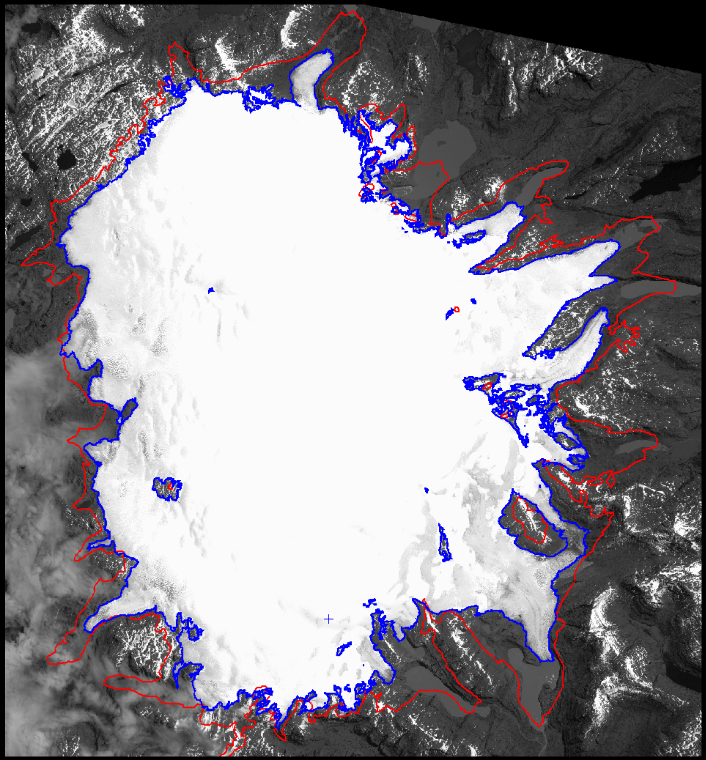


Kerguelen archipelago and Cook ice cap (410 km² in 2001)
Glacier Ampère (67 km², 12.5km length in 2001). *Modis*.

# Observations of glacier wastage

• CIC showed strong negative mass balance since 1950 (Wallon, 1977)
• Extent reduction by 20% in the last 40 years

⇒ How to explain such a wastage?



*Cook ice cap in 1965 (red) and in 2003 (blue). From Berthier et al. (JGR, 2009)*

## Glaciological measurements (LGGE, IPEV project)

- Recent field campaigns (2010-2012)
- Mass balance and meteorological measurements

## Satellite observations (LEGOS)

- Mass balance measurements from 2000

## Geomorphological paleo-datations (LGP) :

- Ampere and Gentil glaciers variations
- Datation with $^{3}He$ / $^{10}Be$ measurements

## Modelling

- Glaciological model
- Reanalysis and CMIP5 models
- Regional climate modelling

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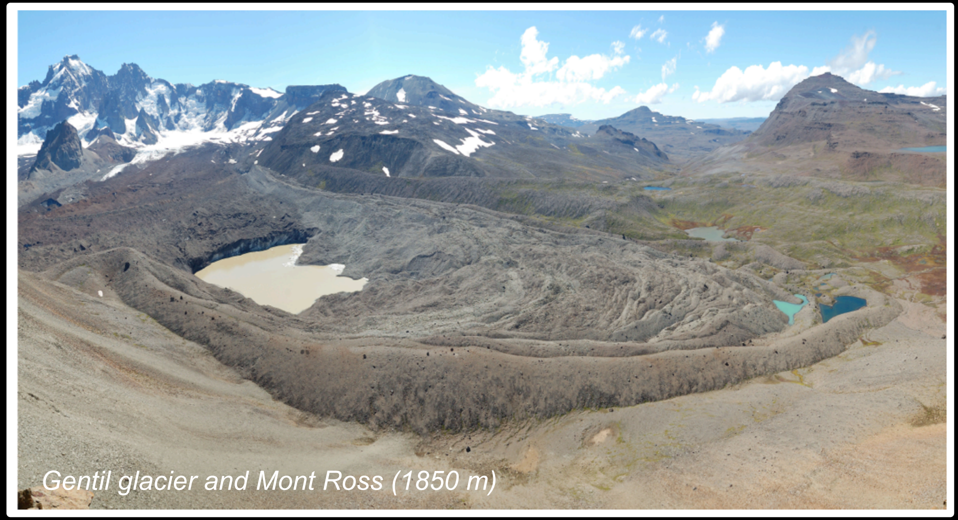


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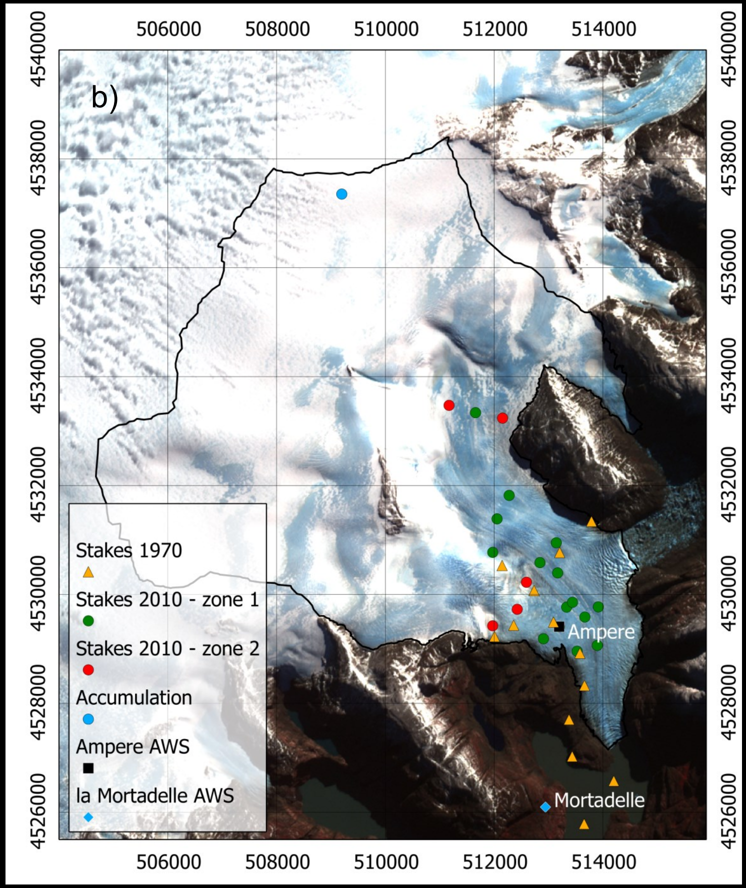
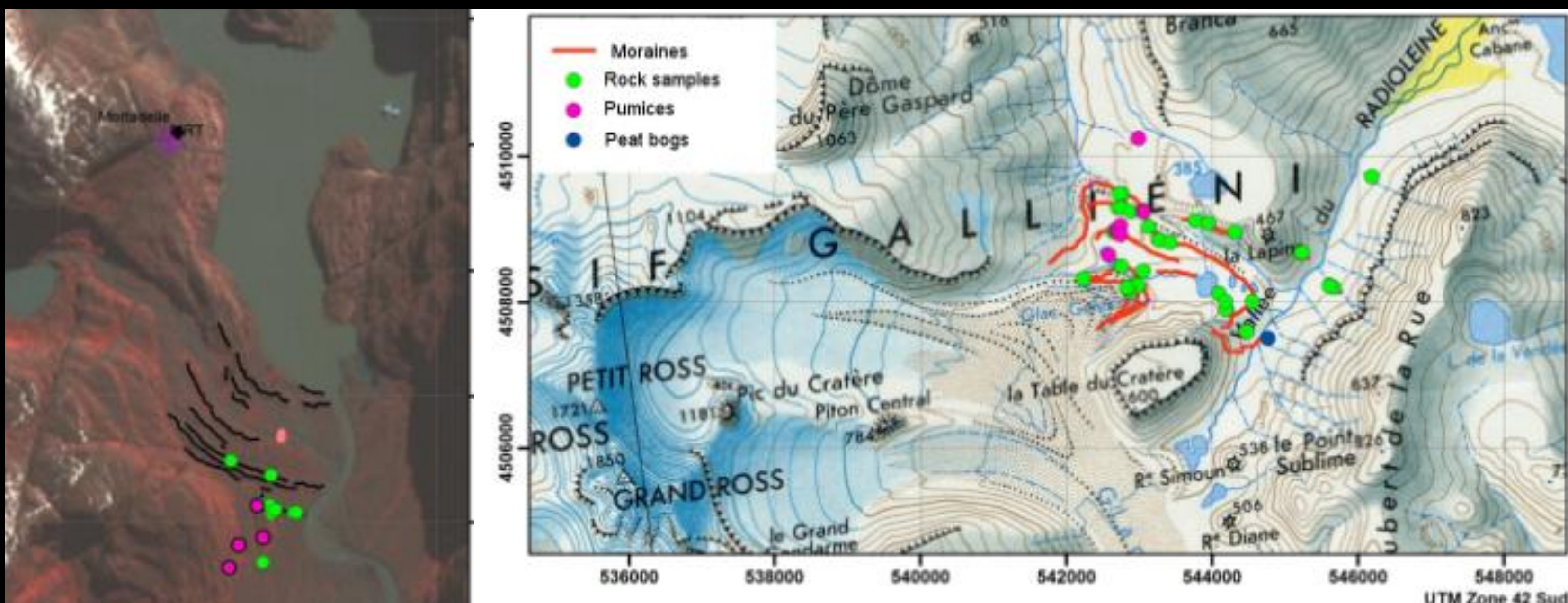
# Field observations (2010-2012)




- Stakes ablation
- Accumulation measurements
- Automatic weather stations
- Radar measurements

# Geomorphological observations

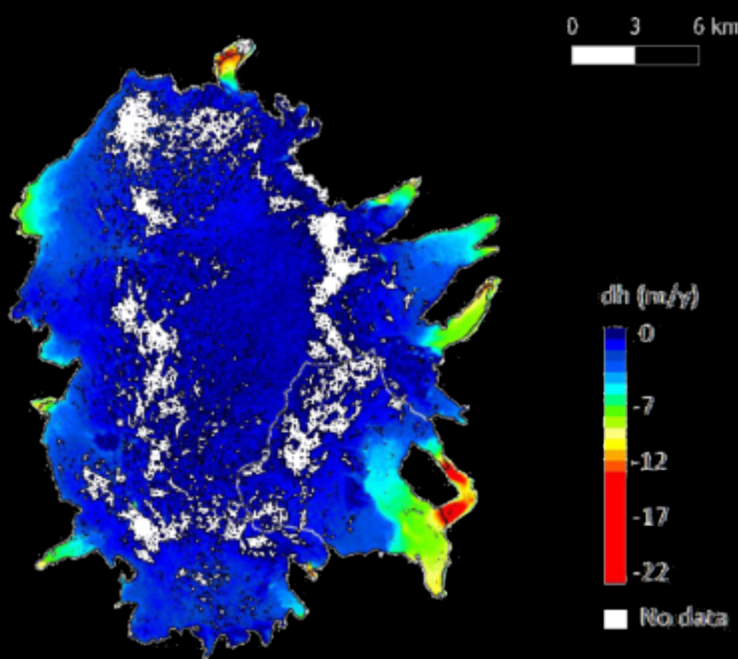
- Ampere : 7 warming-cooling phases (Frenot et al., 1993)
- Current glacier wastage is unprecedented over the period 1800-1950

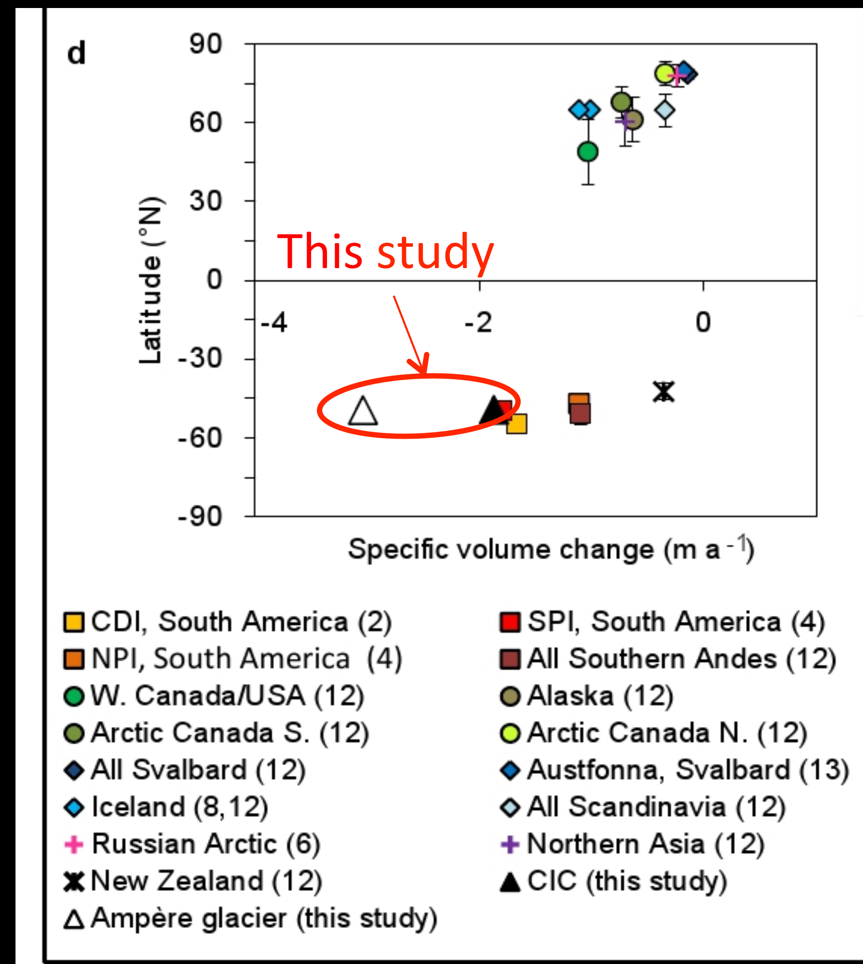


# Ice cap mass balance (2000-2009 observations)

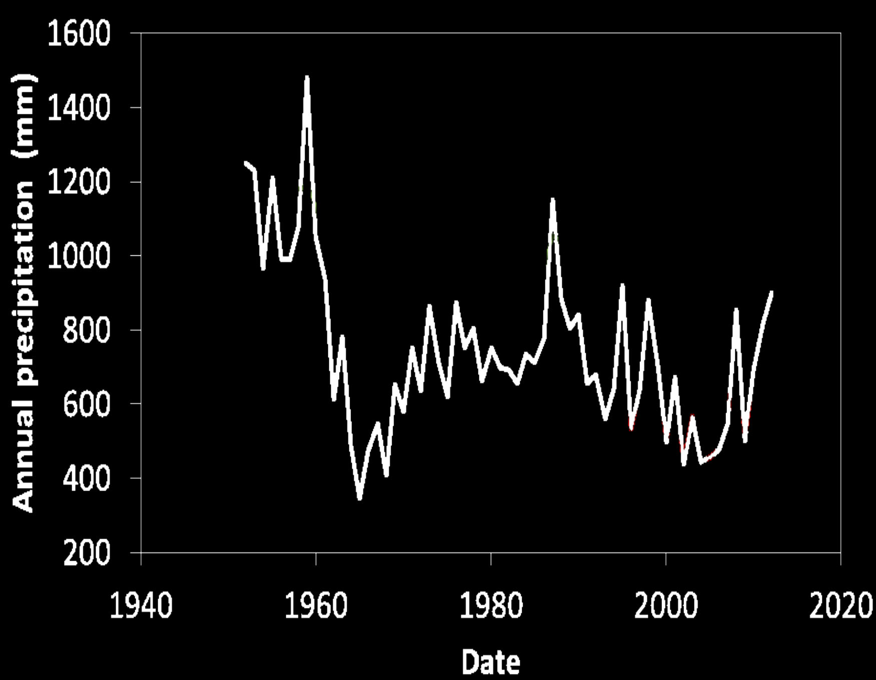
Loss ~ 1.6 m w.eq. $yr^{-1}$

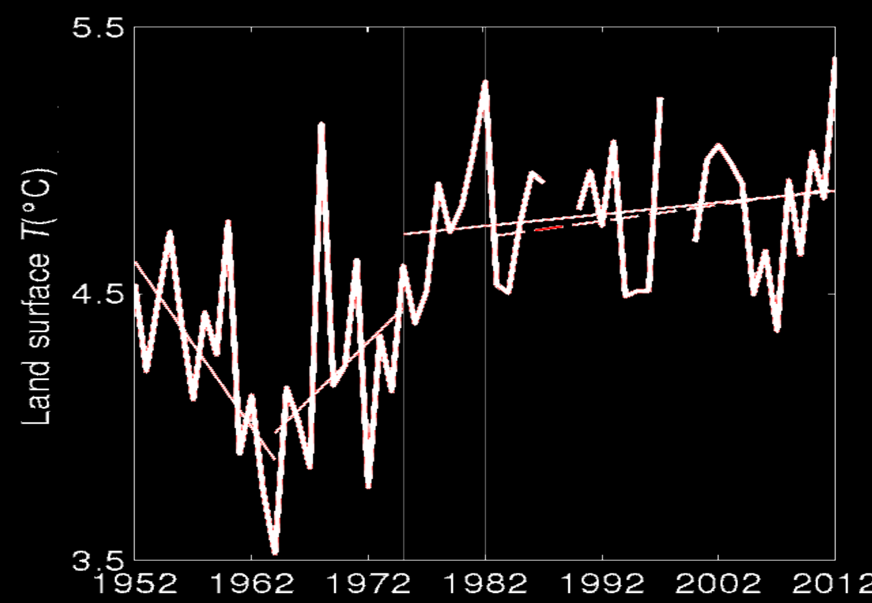
Ampère glacier ~ 2.7m w.eq. $yr^{-1}$



# Local observation of temperature and precipitation



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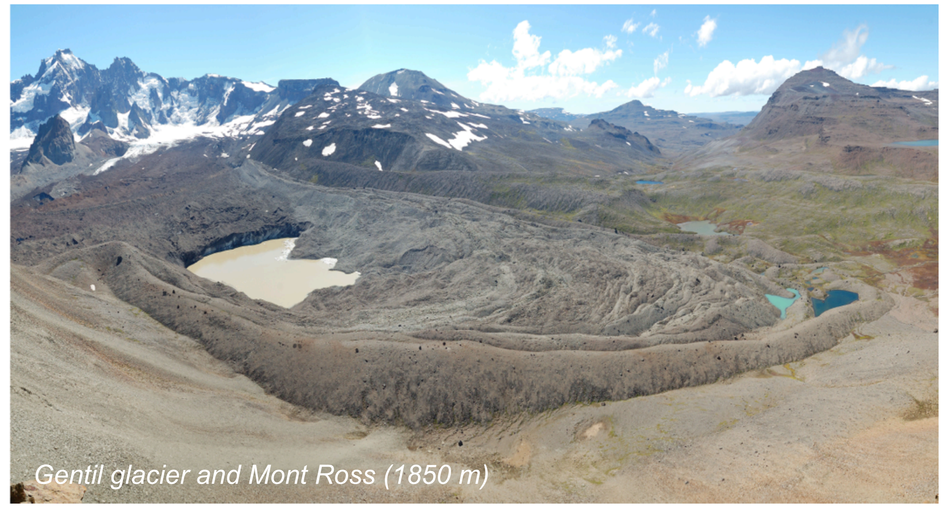


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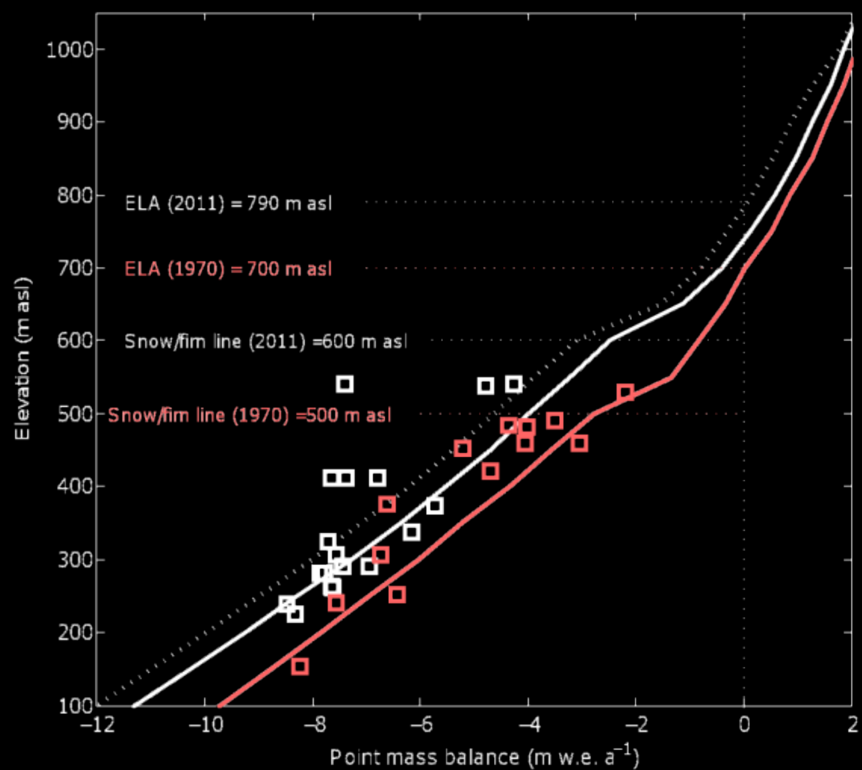
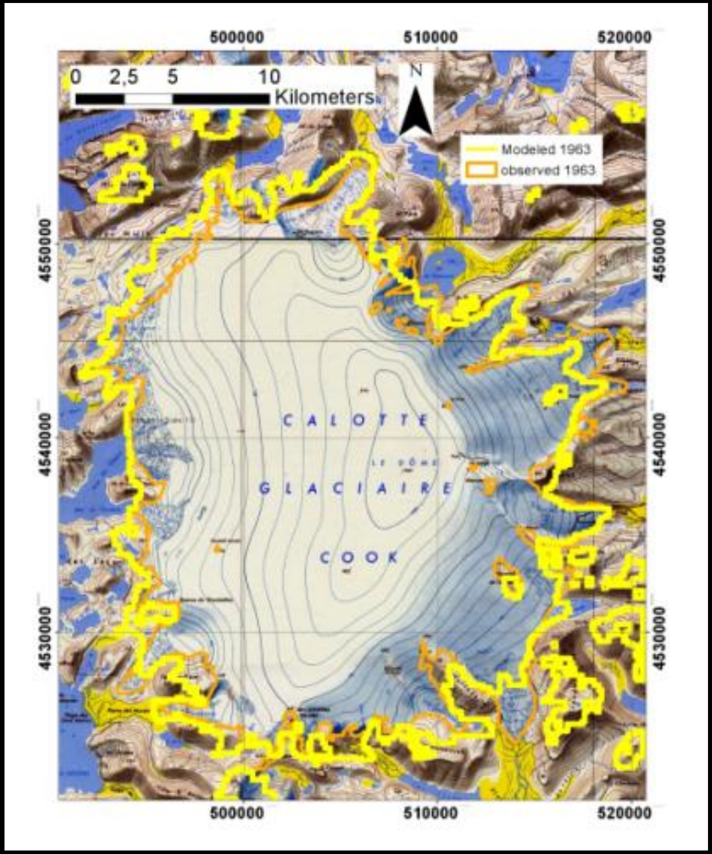
# Mass balance modelling: validation

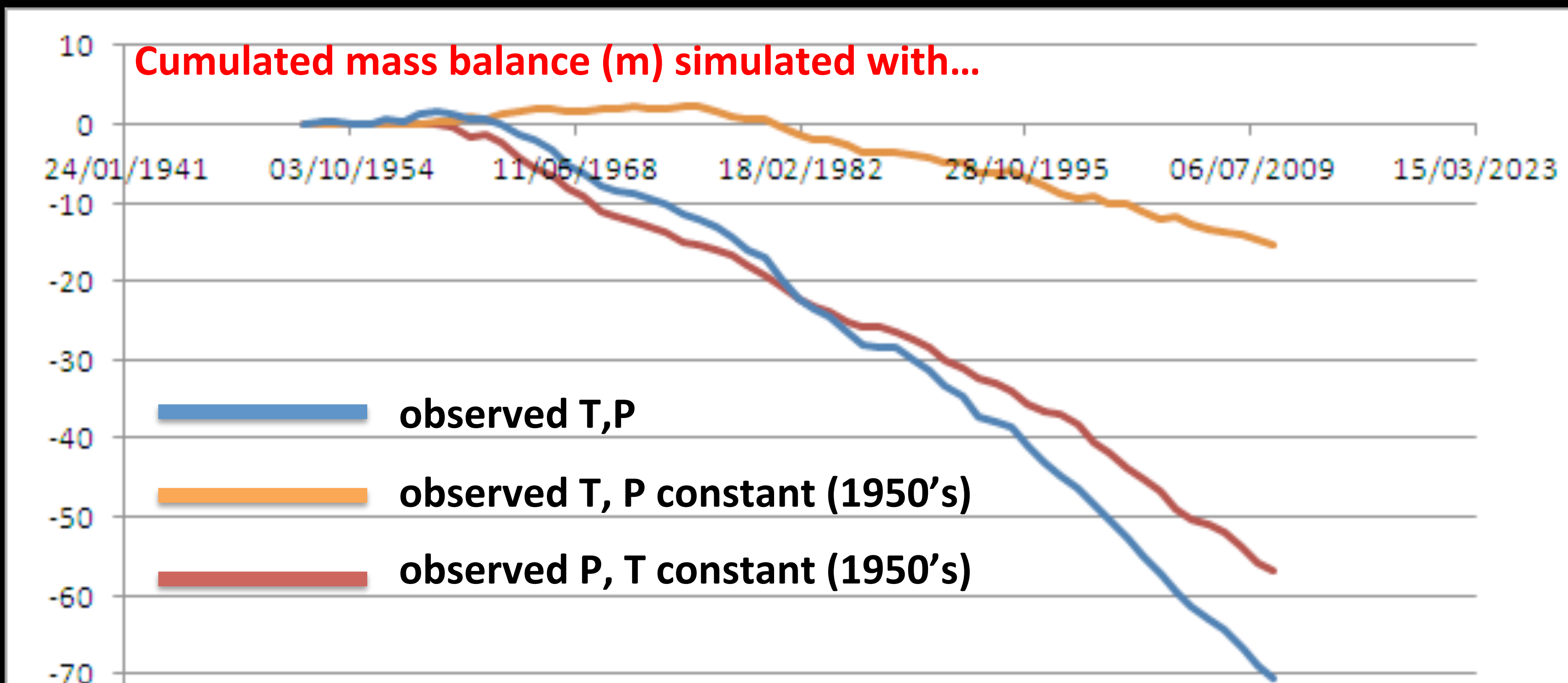



Ampère glacier




Cook ice cap

# Explaining the causes of the wastage




⇒ Over 2000-2009, 77% of the SMB decrease is explained by precipitation reduction with respect to 1950's values

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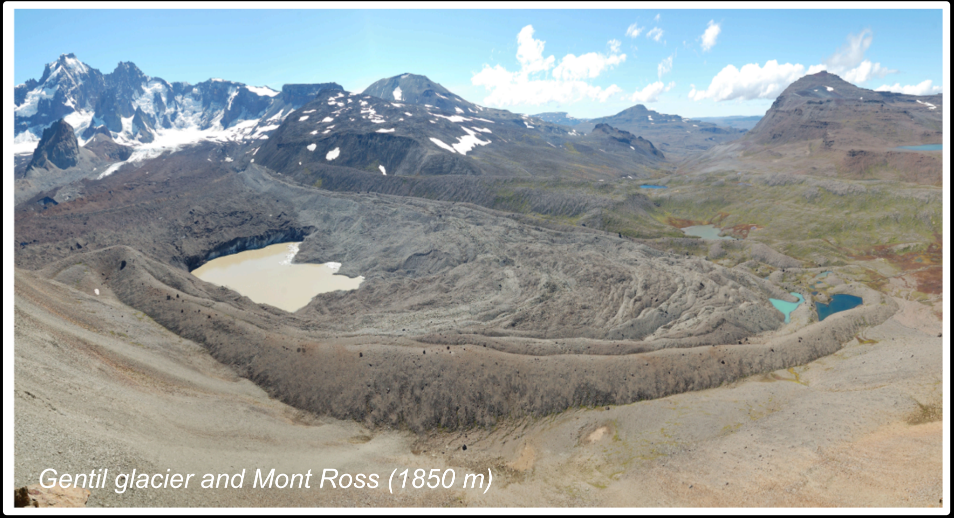


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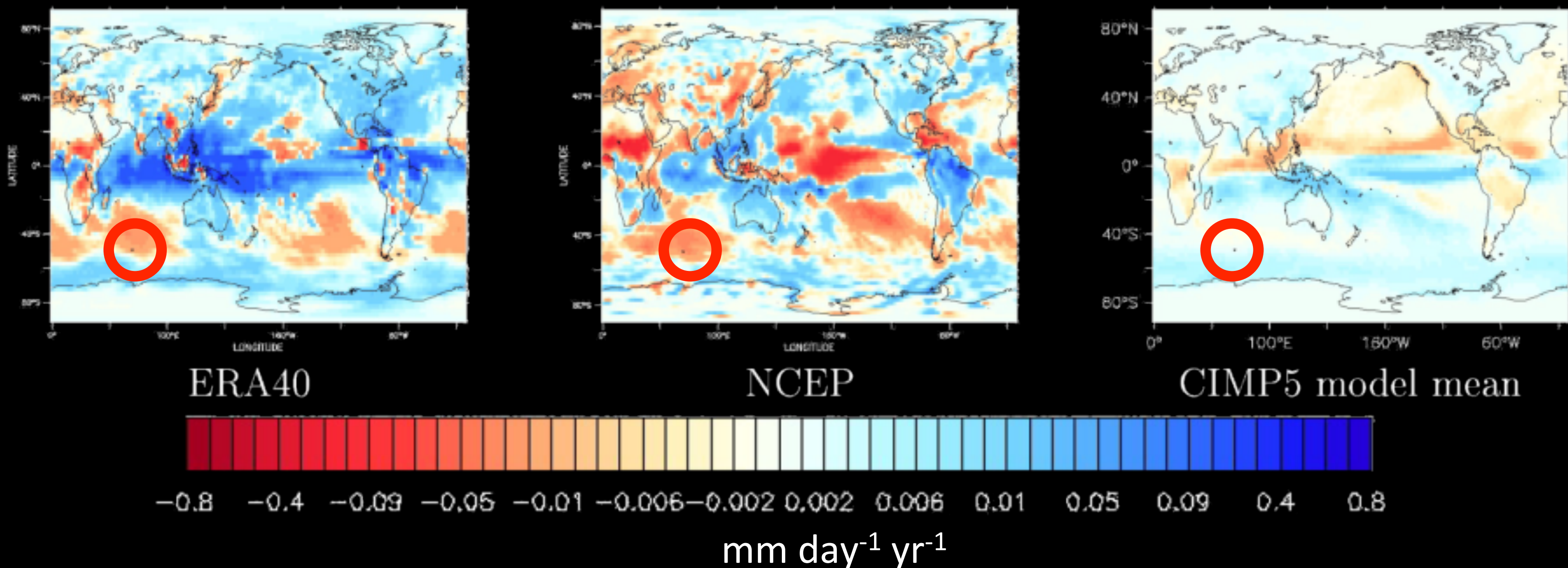
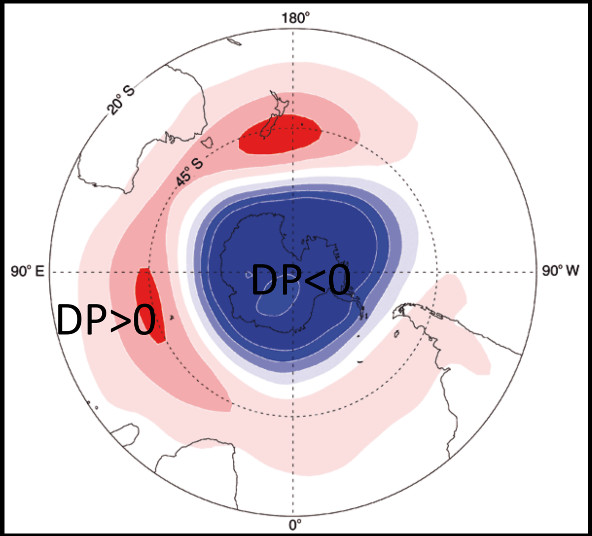
# Precipitation trends in reanalysis

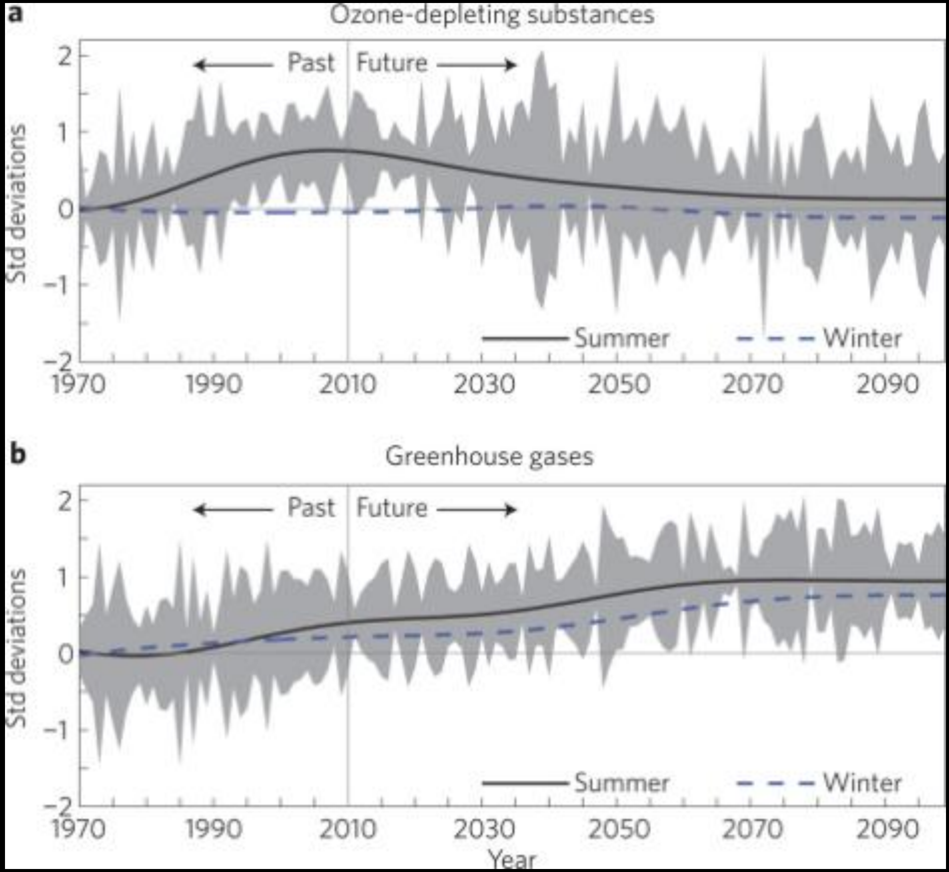


# Southern annular Mode (SAM)



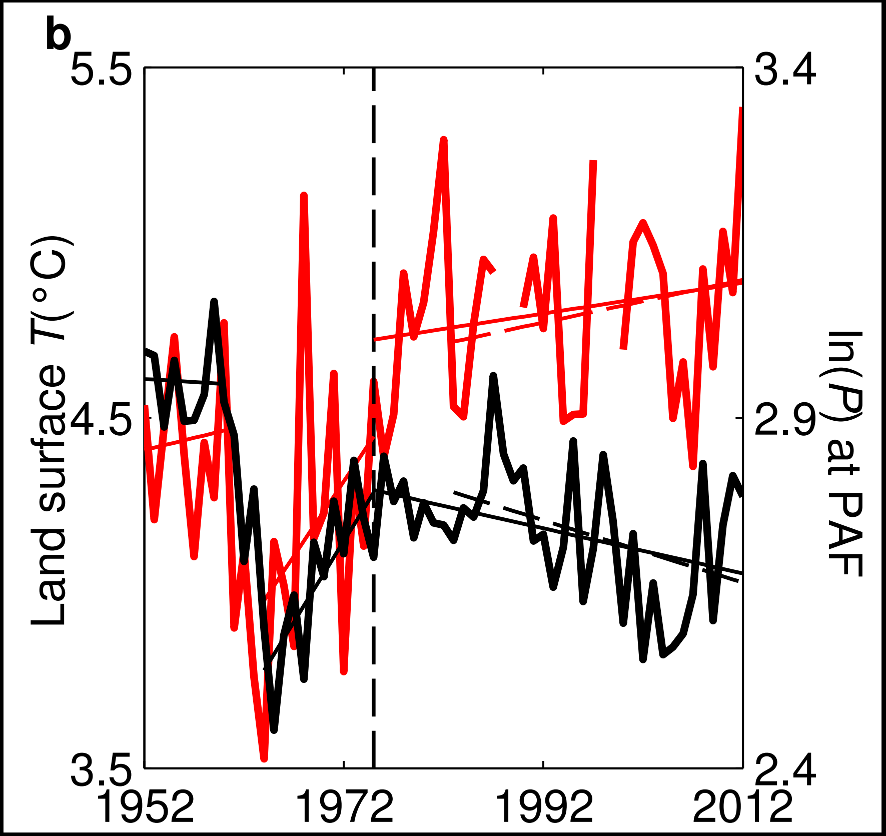

SAM+

Ozone hole and GHGs
=> SAM+



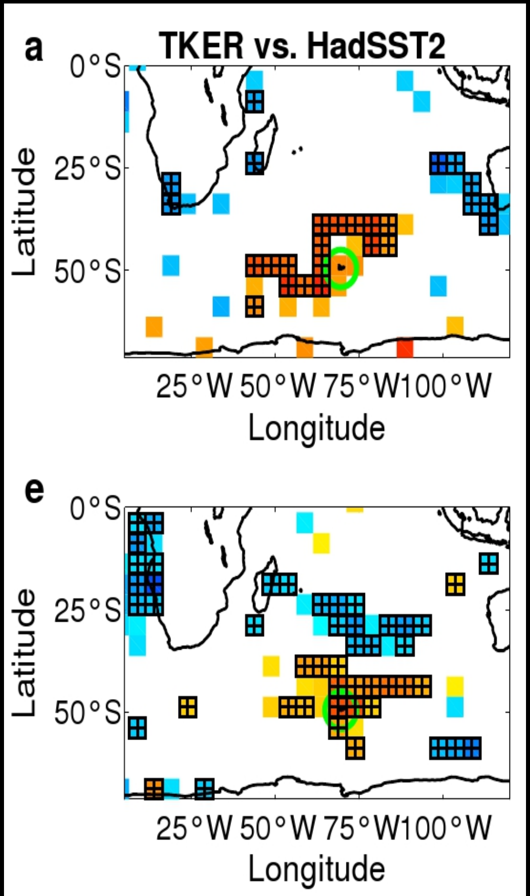

From Thompson et al., NGS, 2011

# Climate change at Kerguelen



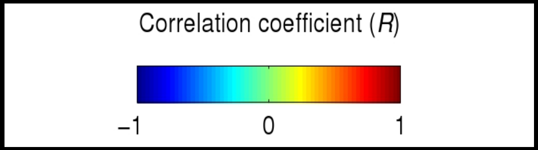

T2m vs. Précipitation

# Temperature and precipitation correlations with SST



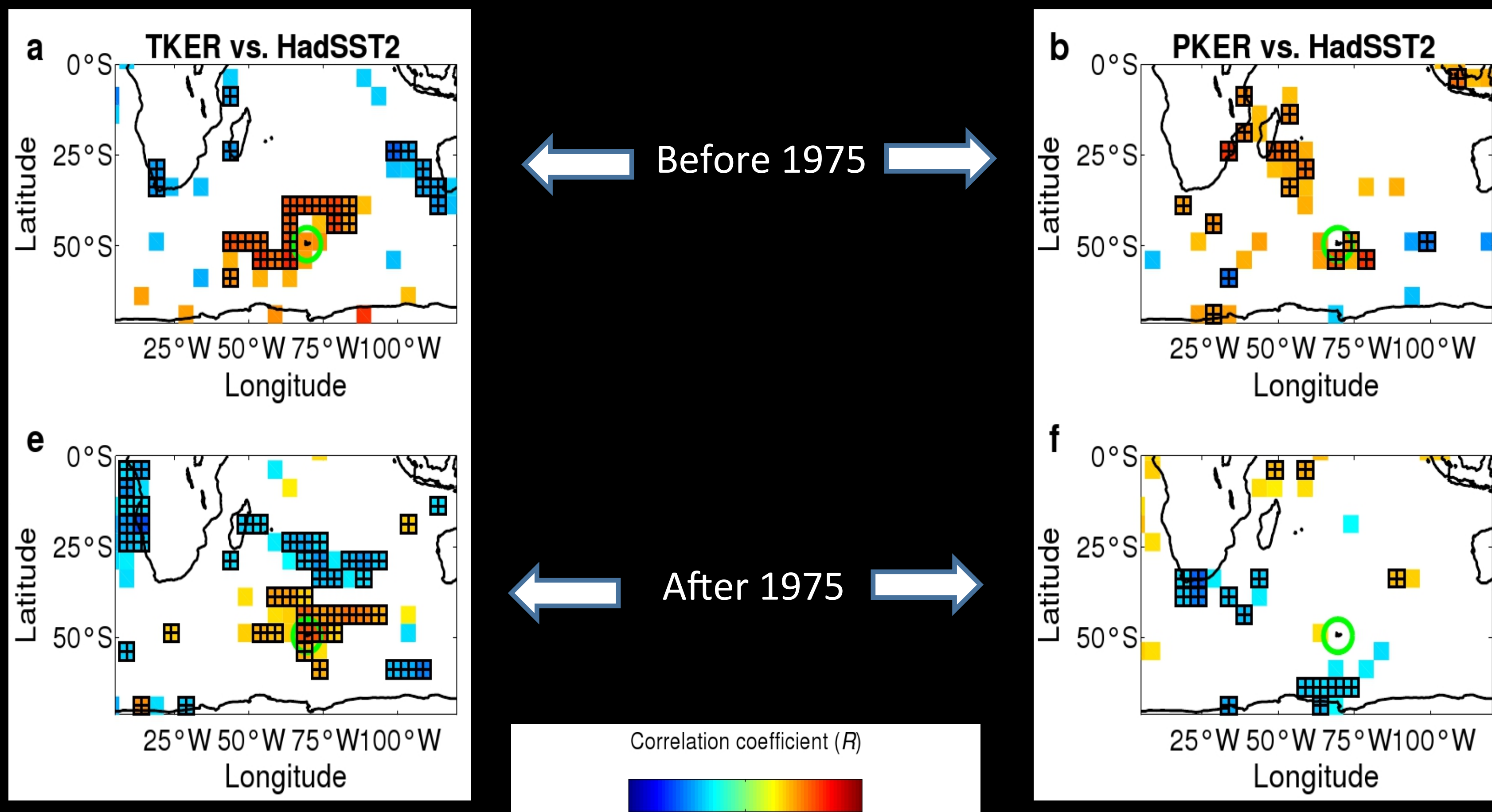

Before 1975

After 1975




T2M versus SST

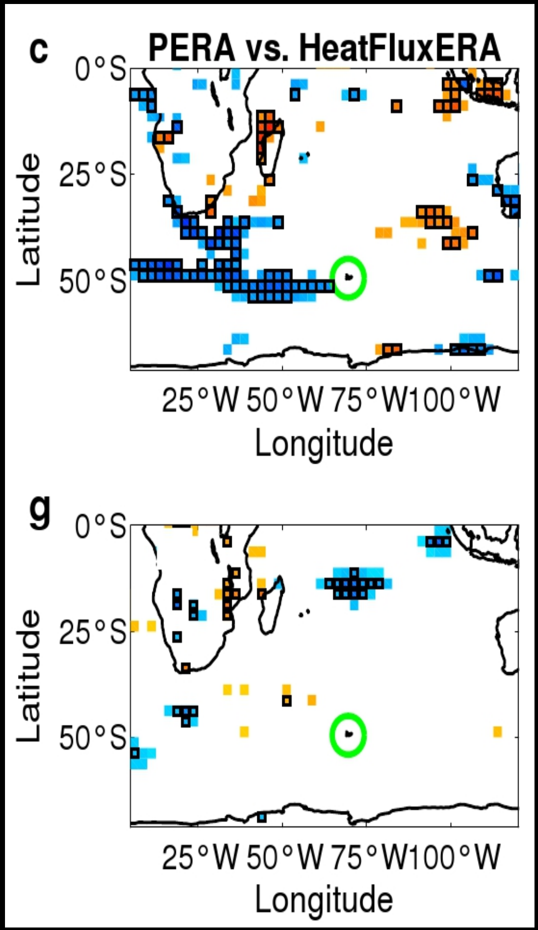
# Temperature and precipitation correlations with SST




T2M versus SST

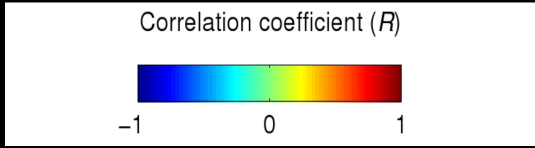
Precip versus SST

# ERA40 correlations



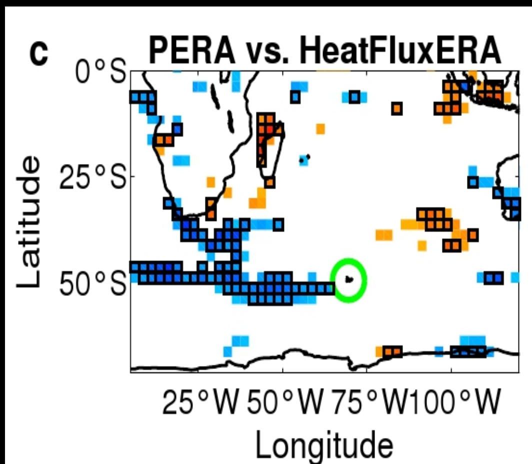

Before 1975

After 1975




T2M versus SST

# ERA40 correlations

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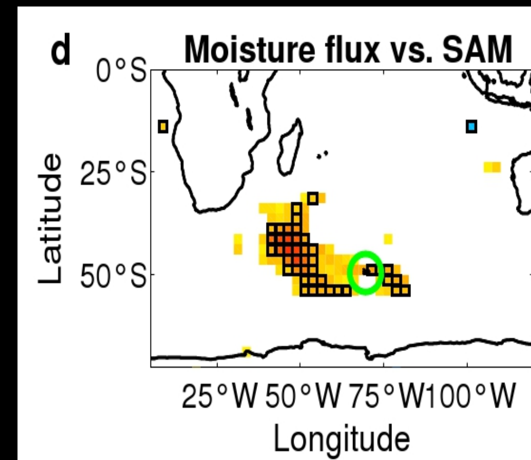
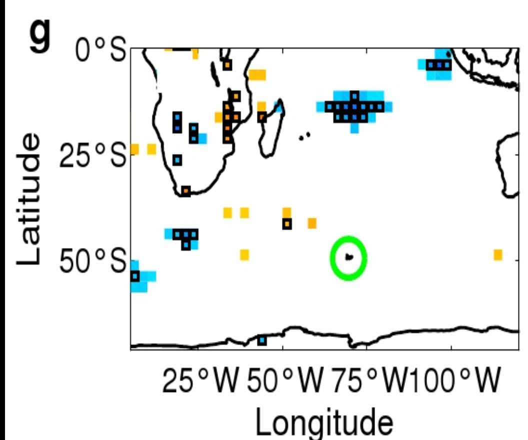
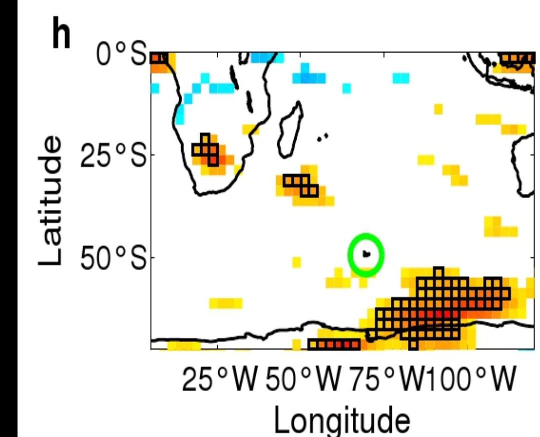
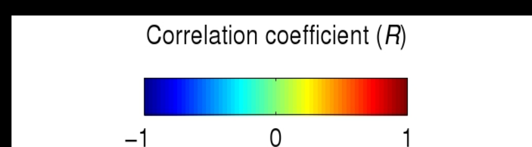



After 1975




T2M versus SST

Precip versus SST

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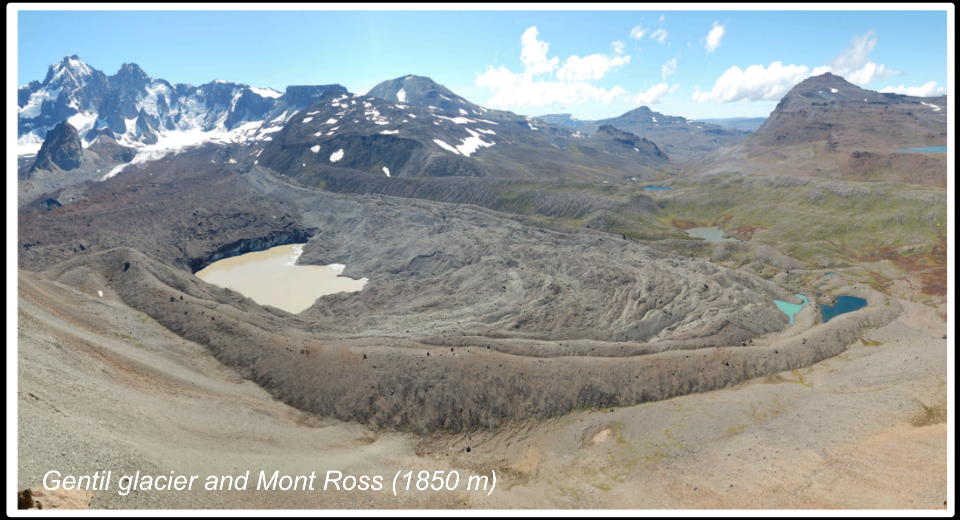


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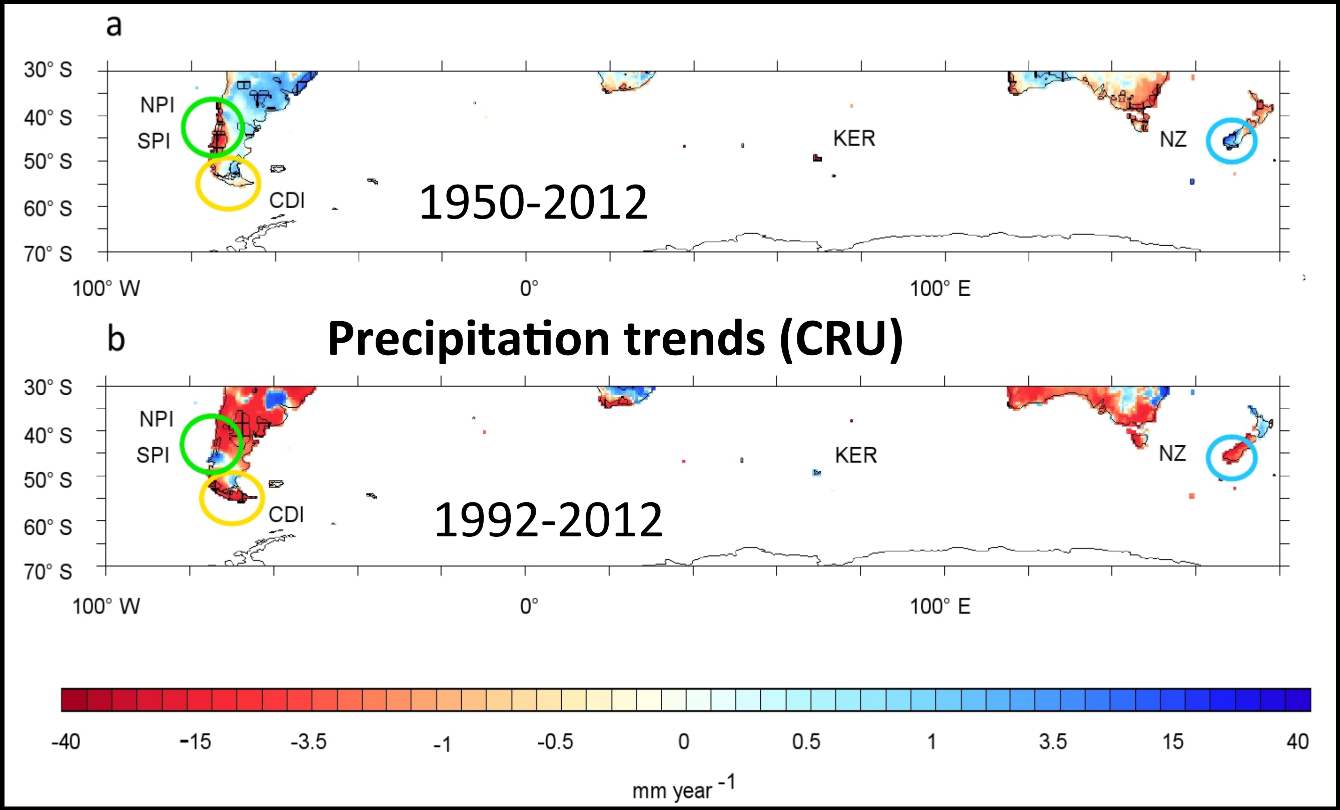
# Conclusions

- The Cook ice cape is highly sensitive to climate change
- Kerguelen glaciers provide useful information on local climate variability (SAM)
- Precipitation was the main driver of the glacier wastage since 1950.
- Climate variability has strongly changed in the Kerguelen area over the last decades.
- The cook ice cap will follow to melt in the future because of warming, whatever the future precipitation trends.

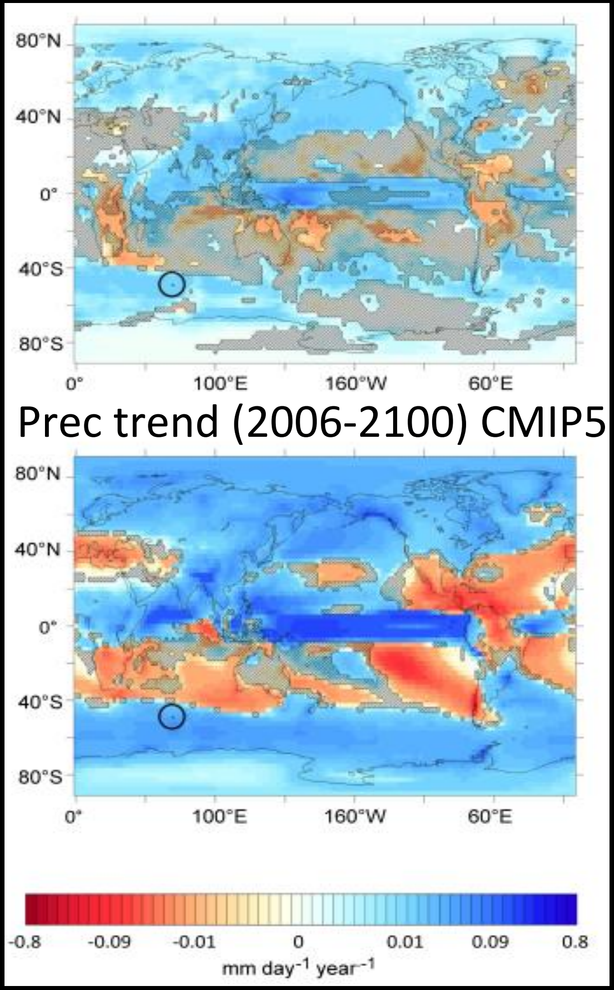
# Outlooks




Glaciers in Patagonia and New Zealand may also have been affected by precipitation decrease

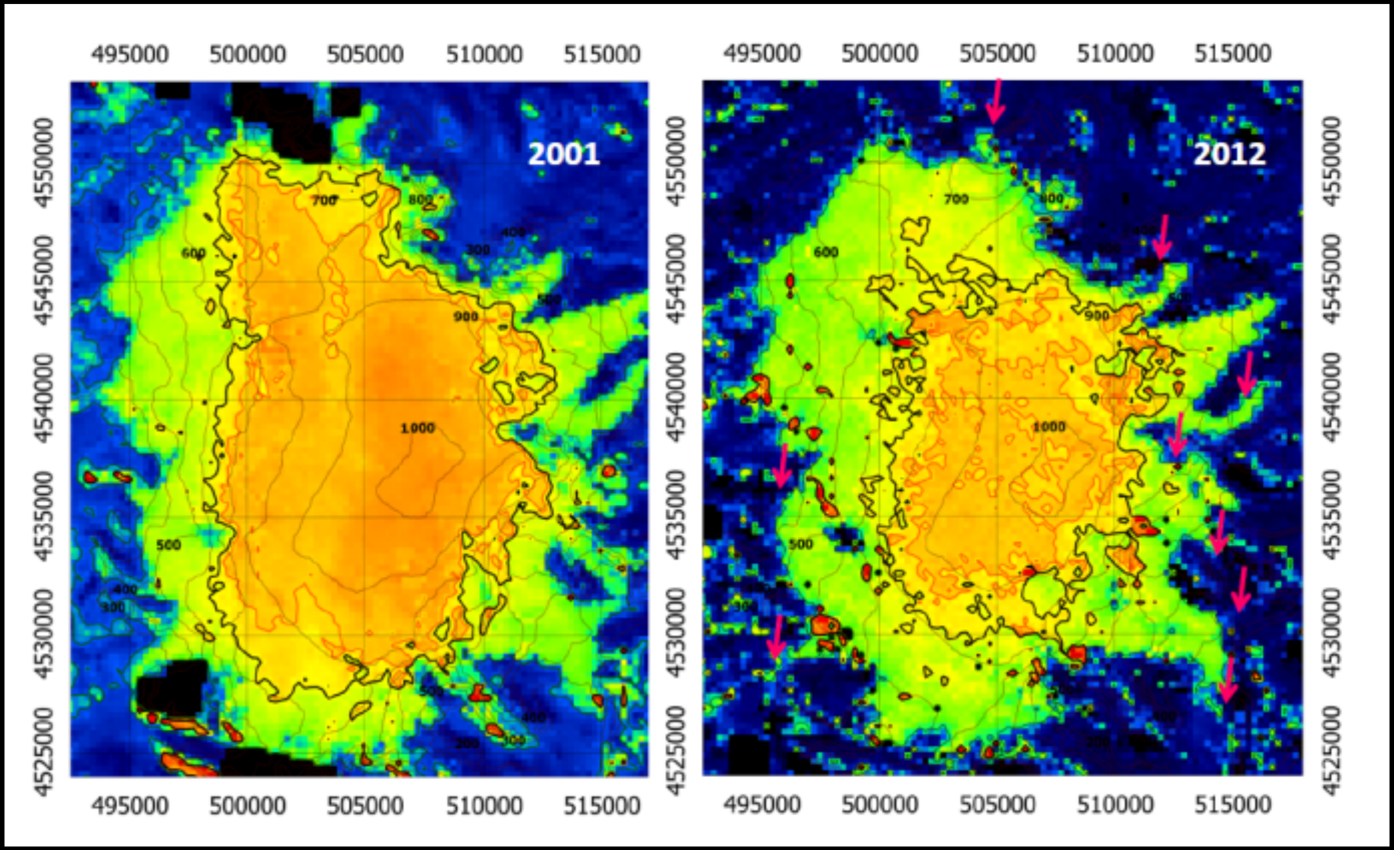
# Thanks you for your attention

# Outlooks




Patagonia, New Zealand and Kerguelen region are located at the border of drying and moistening areas !

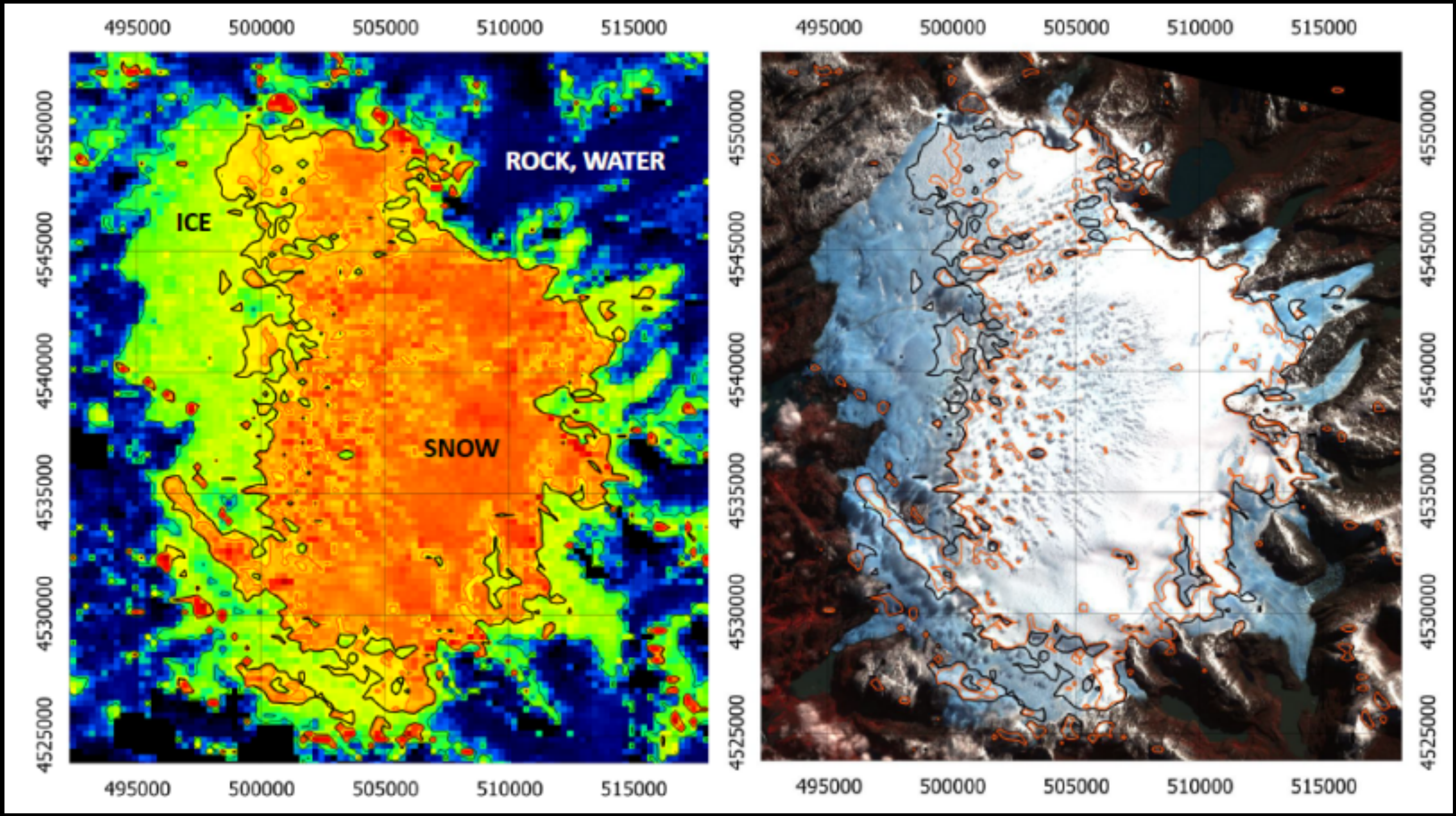
# Remontée de la ligne de neige



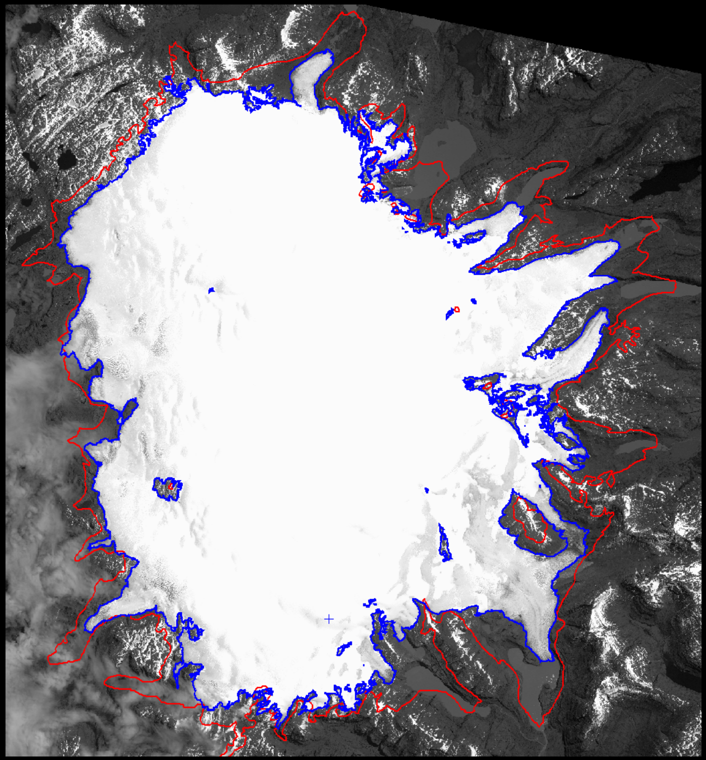

e.g. , à gauche 9 mars 2001, à droite 26 avril 2012

# Importante réduction de la zone d'accumulation

Albédo à partir d'image MODIS (Verfaillie et al., subm.)



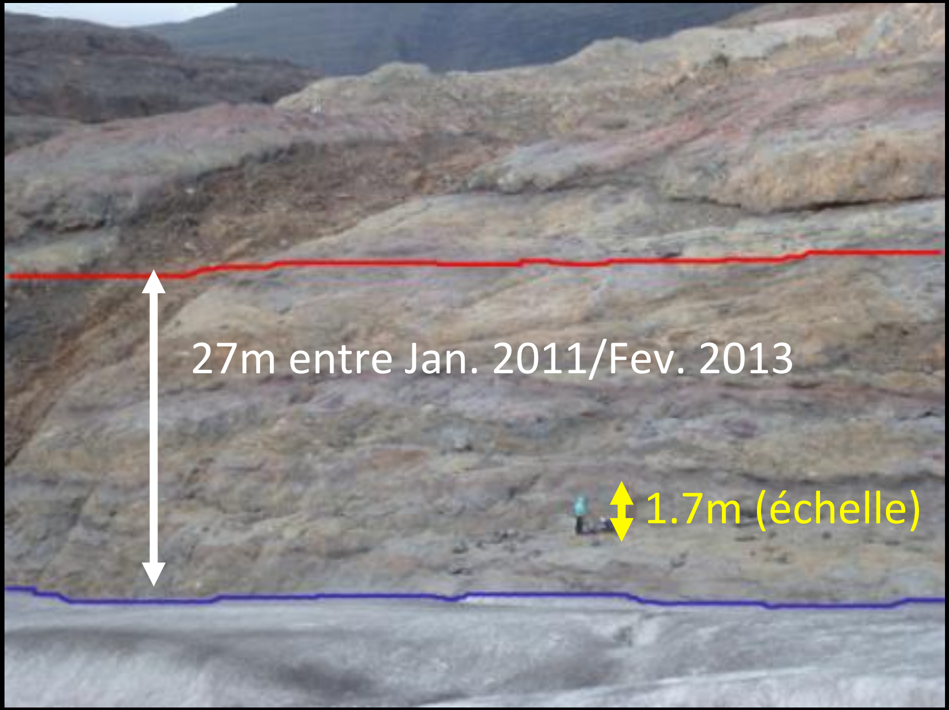
# Variations observées



*Glaciers de la calotte Cook en 1965 (rouge) et 2003 (bleu)*
*D'après Berthier et al. (JGR, 2009)*

- Réduction de surface = 20% en 40 ans
- Forte accélération après 1950

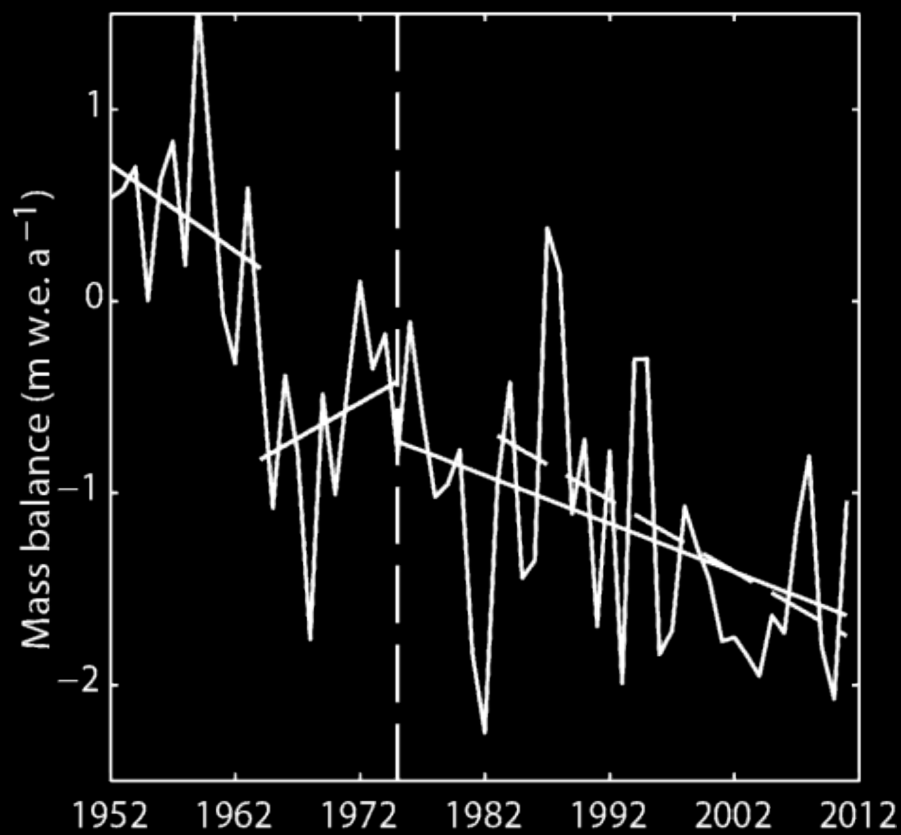
⇒ Quelles sont les raisons du recul?



## Sensitivities expermients

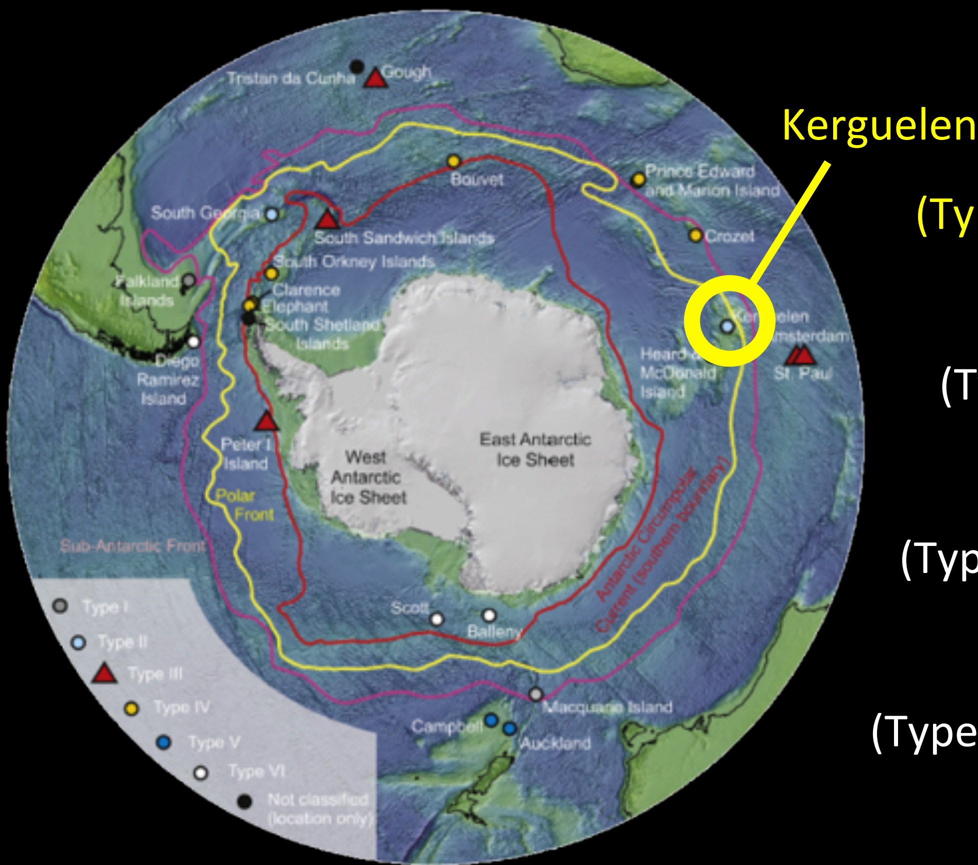
| Without warming | Without drying | Real climate |
|---|---|---|
| 2000-09 | 2000-09 | 2000-09 |
| -1.15±0.08 | 0.07±0.08 | -1.64±0.08 |

# Impact = accélération des pertes




bilan de masse modélisé

# Etat des connaissances (d'après Hodgson et al. in press)




(Type I) little or no LGMice

(Type II) limited LGMice but extensive earlier glaciations

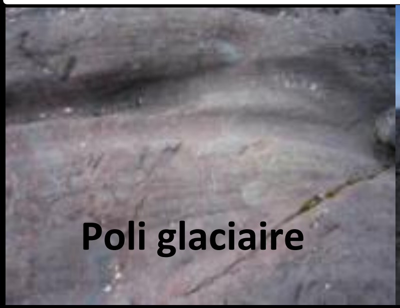
(Type III) seamounts and volcanoes without significant LGM ice

(Type IV) evidence of LGM (and/or earlier) ice expansion

(Type V) north of the Polar Front with evidence of LGM ice

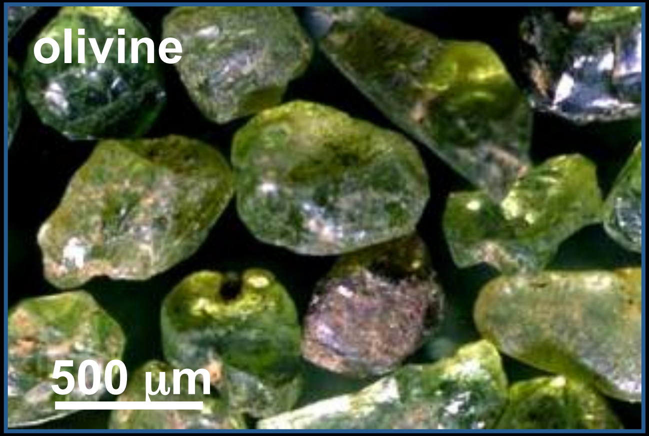
(Type VI) islands with no data

# Datations cosmogéniques



Mesure du $^3He$
cosmogénique




Olivines et pyroxènes

Rétention quantitative du $^3He$ cosmogénique
(non retenu dans le quartz)

# Datations cosmogéniques

- **Gaz rare**
- **Chimiquement inerte**
- **Stable** →
  - ✓ ***Avantage*** **: accès à plusieurs Ma**
  - ✓ ***Inconvénients*** **:**
    - ✓ **composantes non cosmogéniques**
    - ✓ **héritage d'expositions passées**
- **Isotope qui nous intéresse $^{3}$He**

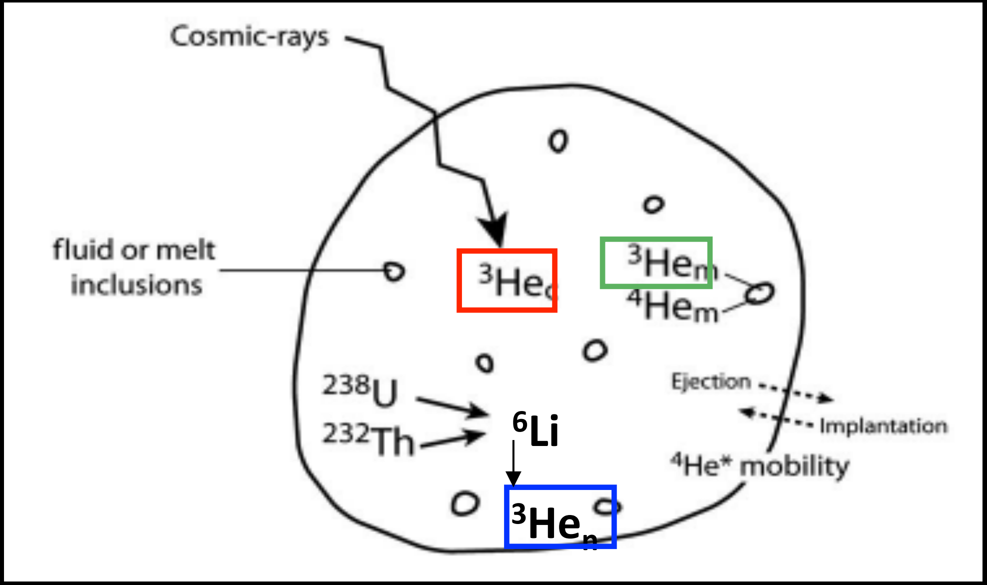
| |
|---|
| **He** |
| Ne |
| Ar |
| Kr |
| Xe |

$^{3}$He : **Cosmogénique**, Magmatique, Nucléogénique

# Datations cosmogéniques

$$^{3}He_{total} = \boxed{^{3}He_{c}} + \boxed{^{3}He_{m}} + \boxed{^{3}He_{n}}$$

**Différentes origines des isotopes de l'hélium dans les minéraux - Corrections à effectuer**




Olivine or pyroxene grain

Blard P.-H. and Farley K.A. , The Influence of radiogenic $^{4}He$ on cosmogenic $^{3}He$ determinations in volcanic olivine and pyroxene, *EPSL*, **276**, 20-29 (2008)

# Datations cosmogéniques

## Résultats préliminaires